Developments in the Manufacture of Lead-Covered Paper-Insulated Telephone Cable *

By JOHN R. SHEA

This paper describes developments in the manufacture of lead covered paper insulated telephone cable completed during the past three years. The introduction describes the manner in which cable is used in the telephone system and briefly outlines the manufacturing processes and equipment as they existed about three years ago. The new developments are then treated in considerable detail, the most outstanding of which are the application of wood pulp insulation direct on the wire instead of spirally wrapping manila rope ribbon paper; new equipment for vacuum drying and storing cable in which a large storage room of unique construction is provided with conditioned air at a relative humidity of .5 per cent at 100° F.; the central melting of large quantities of lead alloy and its distribution through piping systems to a number of lead presses; improved and larger sheathing presses; and precision electrical testing of the finished cable. Most of these improvements are incorporated in the new Baltimore Cable Plant of the Western Electric Company.

PAPER-INSULATED lead-covered telephone cable constitutes approximately 25 per cent of the Bell System telephone plant. The cost of new telephone cable each year, including installation, averages $100,000,000. Developments in the process and equipment for its manufacture are numerous and have been a large contributing factor in the establishment of a high standard of service in the long-distance communication field. The problems involved in manufacturing engineering are extremely interesting both from an economic and technical standpoint to the mechanical and the electrical engineer, the physicist, and the chemist, and the illustrations which follow contain fundamental engineering principles of use in many lines of industry.

Before proceeding directly with these problems, a brief outline of how cable and its associated apparatus function in the long distance communication field will be of value. After presenting this broad picture, the bulk of the paper will be devoted to an engineering discussion of developments in the process and equipment for manufacturing cable as illustrated by recent improvements introduced in the new cable plant of the Western Electric Company at Baltimore and at the Kearny, New Jersey, and Chicago plants.

* Presented at A. S. M. E. meeting, Cleveland, Ohio, April 13–17, 1931. Published in abridged form in Mech. Engg., April, 1931.

General Information on Use of Cable

The rapid increase with which cable is being added to the toll plant is illustrated quite strikingly by Fig. 1, which shows the present and proposed increases in cable in comparison with open wire and carrier

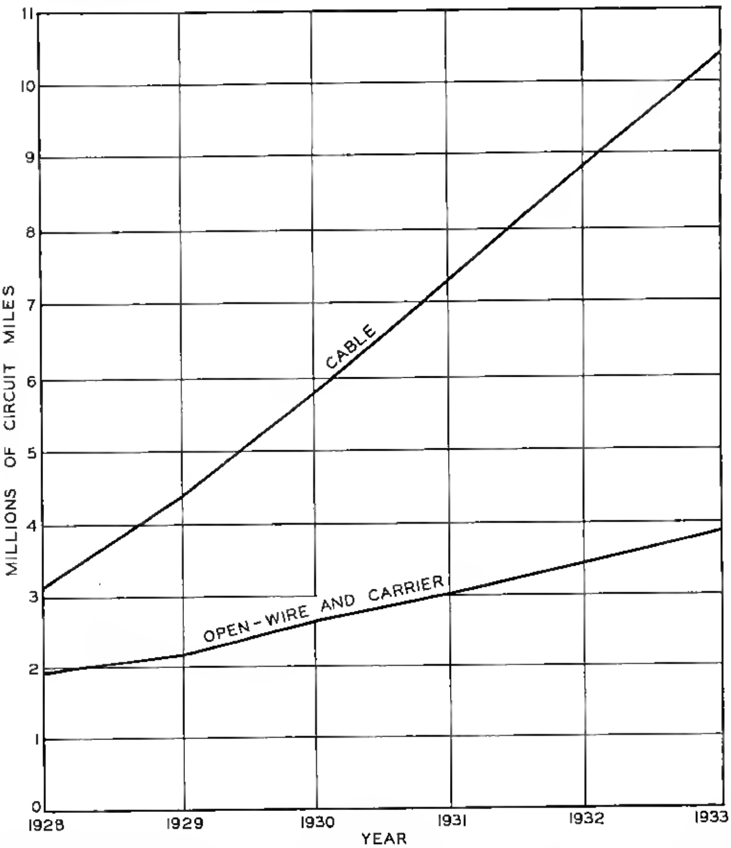


Fig. 1—Present and proposed increase in cable in comparison with open wire and carrier circuits.

circuits.[1] The future scope of this expansion is shown by Fig. 2, which indicates the present and proposed main toll cable routes in the United States. The exact program on which these cables will be extended will depend upon how rapidly the business develops; however, definite future plans have been outlined to extend the cable to Omaha, Nebraska,** and across the continent to San Francisco, thus replacing and increasing the capacity of existing open wire lines.

[1] "Recent Developments in Toll Telephone Service" by W. H. Harrison, *Jour. A. I. E. E.*, March, 1930; *Bell Telephone Quarterly*, April, 1930.

** This cable was completed in May, 1931.

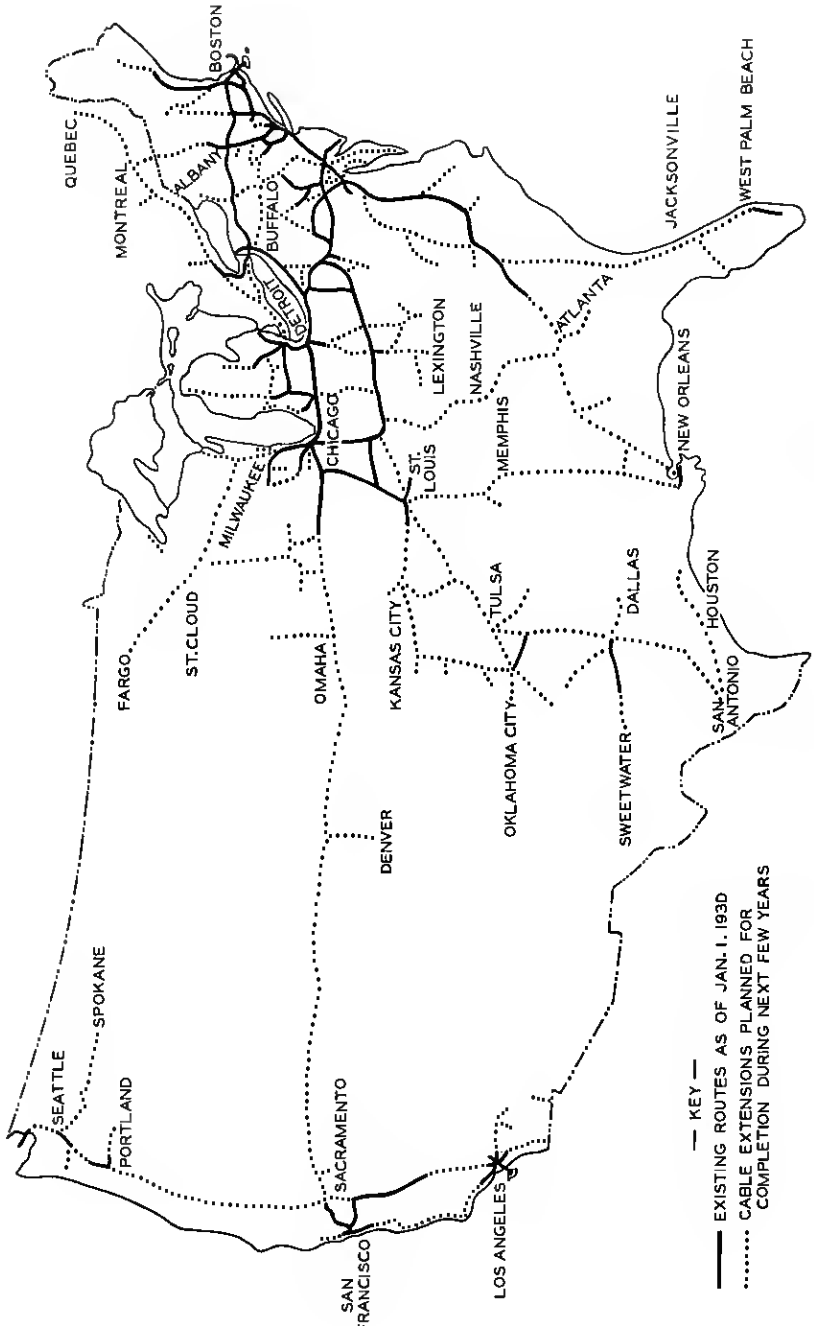


Fig. 2—Main toll cable routes of United States and Canada.

The elements of a typical cable route are illustrated in the New York to Pittsburgh cable chart shown in Fig. 3. A Pittsburgh call originating at a subscriber's station, for example, in Yonkers, New York, passes through the toll board of the local telephone exchange to the toll center located at Walker Street, New York City. At this point the connections are completed for the call to Pittsburgh through the toll cable circuits and repeater stations between the two cities.

The speech currents as they travel along this circuit diminish in intensity. Loading coils placed along the cable circuit at regular intervals reduce these losses to a considerable degree but even with

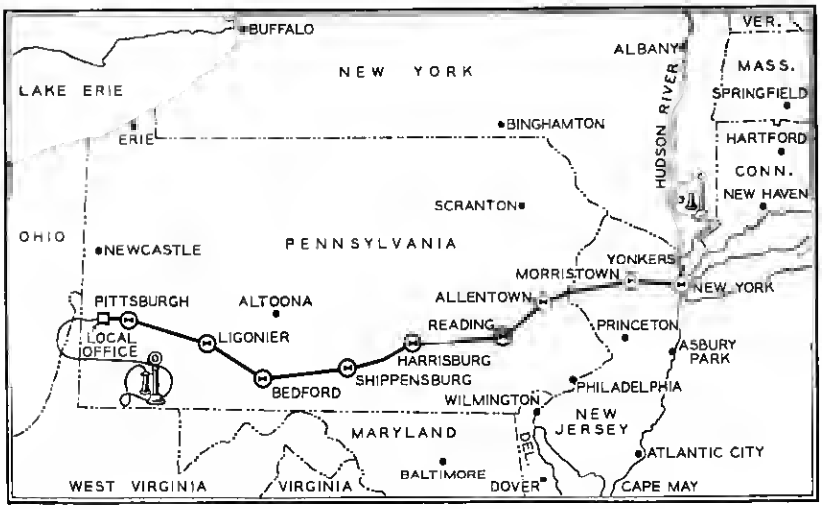


Fig. 3—Typical cable route.

these it is necessary to supply amplifiers (repeaters) [2, 3] at intervals of approximately fifty miles to boost the energy level.

The amount of amplification required for intelligible speech varies with the resistance of the cable conductors which changes with the temperature. In order to regulate the amount of the amplification to compensate for these variations, what is known as a pilot wire regulator is installed at certain repeater points which automatically adjusts the gain of the repeaters to correct for the changing line losses.

Difficulty is also experienced on long toll lines due to the voice currents being reflected back to the speaker. To prevent this, a device is provided which automatically short circuits one side of the

[2] *A. I. E. E. Transactions* (1919), Vol. XXXVIII, Part 2, "Telephone Repeaters," by Bancroft Gherardi and Frank B. Jewett.

[3] *A. I. E. E. Transactions* (1923), Vol. XLII, "Telephone Transmission over Long Cable Circuits," by A. B. Clark. *Bell. Sys. Tech. Jour.*, Jan., 1923.

line while speech is being transmitted in the opposite direction on the other side. This device is known as an "echo suppressor." [4]

The enormous increases in long distance telephone traffic together with the necessity of providing better transmission quality in connection with radio broadcasting [5] and trans-oceanic messages, have led to continuous design changes in telephone plant with more exacting requirements for manufacture. To permit adequate and predetermined spacing of loading coils and repeater stations, the cable design must be such as to insure definite capacitances per mile. There must be a minimum of unbalance between circuits to insure that interference or "crosstalk" is held to a low value. To handle the ever increasing load of messages promptly and to secure further overall economies, cables are being designed with a greatly increased number of wire pairs, but of approximately the usual outside diameters to permit the use of existing cable ducts. All of these design problems are reflected in the machinery and methods of manufacture.

Manufacture of Cable [6]

A typical long-distance telephone cable (toll cable) consists of "quads" (double pairs) of paper-insulated electrolytic copper wire (No. 16 to No. 22 B. & S. gauge) built up in layer construction and covered with a lead-antimony alloy sheath $2\frac{5}{8}$ in. in diameter and $\frac{1}{8}$ in. thick. (Fig. 4.)

The raw materials for such cable consist of high-grade lead in pig form, annealed electrolytic copper wire, and large jumbo rolls of manila-rope wood-pulp paper. The first operation consists of slitting the large rolls of paper into disk-shaped pads (Fig 5). A sufficient number of these pads are placed in an insulating machine which applies the paper to the copper wire in spiral form at a head speed of from 1,470 to 2,400 r.p.m. (Fig. 6). The insulated wires are paired very carefully and then placed in a machine which first twists the pairs and then forms them into twisted quads (Fig. 7).

The quads of wire thus built up are placed into a strander. One quad serves as a center about which other quads are laid in alternate layers as the material progresses through the machine (Fig. 8). Step

[4] *A. I. E. E. Proceedings*, Vol. XLIV, "Echo Suppressors for Long Telephone Circuits," by A. B. Clark and R. C. Mathes.

[5] *Bell Sys. Tech. Jour.*, July 1930, "Long Distance Cable Circuit for Program Transmission," By A. B. Clark and C. W. Green.

[6] See paper "Recent Developments in the Process of Manufacturing Lead-Covered Telephone Cable," by C. D. Hart, for historical treatment and developments prior to 1927—presented at the Regional Meeting of District No. 5 of the A. I. E. E., Chicago, Illinois, November 28 to 30, 1927. Published in *Bell Sys. Tech. Jour.*, April, 1928.

by step it is thus built up, one layer being applied by each drum until the full amount is obtained, after which an outer wrapping of paper is applied to retain the insulated wires in shape and also serve as an additional insulation from the lead sheath.

All telephone cable for local service (exchange cable) until recently was made in much the same manner. Recently two new processes have completely revolutionized its manufacture.

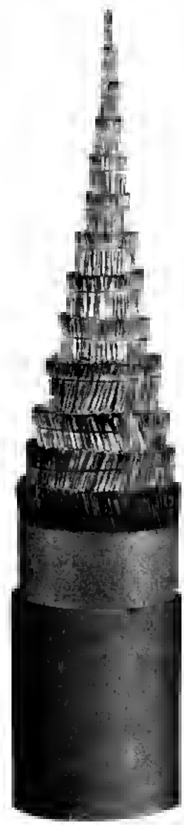


Fig. 4—Typical construction of long distance telephone cable.

Direct Application of Wood-Pulp Insulation

The process and machine recently developed to apply wood pulp direct on wire combines the steps of paper making, slitting, (Fig. 5) and insulating (Fig. 6) into one operation, and gives a continuous sleeve of pulp paper around the wire.

Essentially, the process consists in forming simultaneously on a

modified cylinder paper machine, 50 narrow continuous sheets of paper, with a single strand of wire enclosed in each sheet, pressing the excess moisture from the sheets, turning them down by means of a rapidly rotating polishing device, so as to form a uniform cylindrical coating of wet pulp around the wire, and then driving the water from this coating by drying.

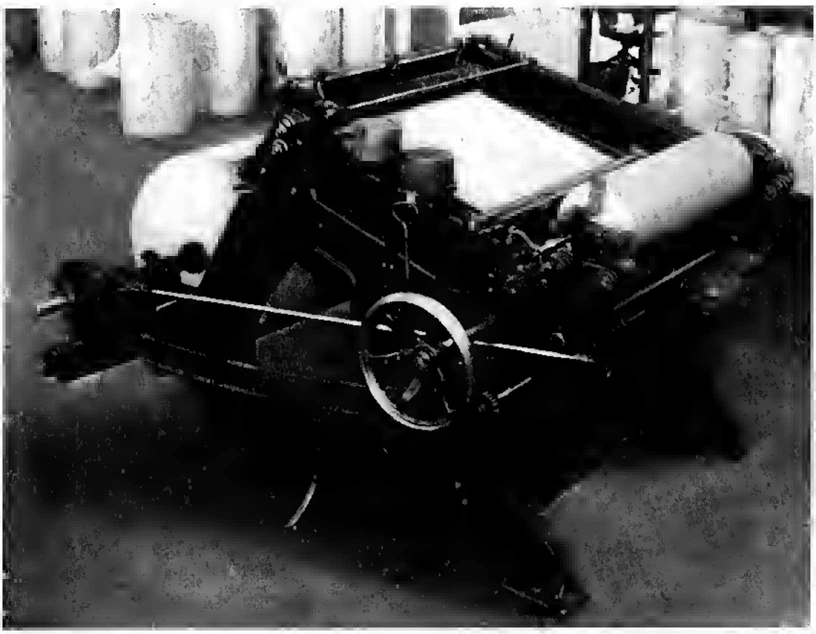


Fig. 5—Slitting of paper.

The material used in making this insulation is Kraft pulp, which is prepared for use on the machine by beating as in the ordinary paper-making operation (Fig. 9) and fed to the machine in a somewhat more diluted form than in standard paper making practice.

In theory, the whole process is simple, but from a practical standpoint, many interesting problems had to be solved before satisfactory operation was possible. A continuous supply of wire must be furnished, as it is not feasible to shut the machine down to change supply spools. This was taken care of by removing the wire from the supply spool by means of a flier without rotating the spool. This allows time to braze the end of the wire from one spool to the next. Ordinary annealed copper wire has a non-uniform surface due in part to the residual drawing compound. A satisfactory surface is obtained by

passing the wire through an alternating-current electrolytic cleaning bath before it enters the paper forming machine. A narrow sheet is formed on each conductor in an ordinary single-cylinder paper machine, the mold of which has been divided into 50 parts by means of celluloid strips and so arranged that a part of the sheet of paper is formed before the wire comes in contact with it. The remainder of the sheet is then laid down on top of the wire without any break in the formation,

Fig. 6—Paper insulating machine.

and the resulting narrow ribbon of paper carries the wire imbedded in it. Thus fifty conductors are being insulated simultaneously. Two sets of press rolls take the excess moisture from the sheet, and leave it ready for the polishing operation. Various types of polishers have been developed and the one now in use consists of two short, specially shaped blocks, with a third block located about centrally to the other two. These polishers are rotated very rapidly around the wire

(Fig. 10). Their construction is such that if an occasional lump or break occurs in the sheet it does not cause clogging of the polisher. Polished wet insulation carries about 70 per cent water by weight, which has to be driven off by heat. The drier consists of a 25-ft.-long electric box-type furnace, with heating elements extending the full length of the top, and additional heating elements in the first 8-ft.

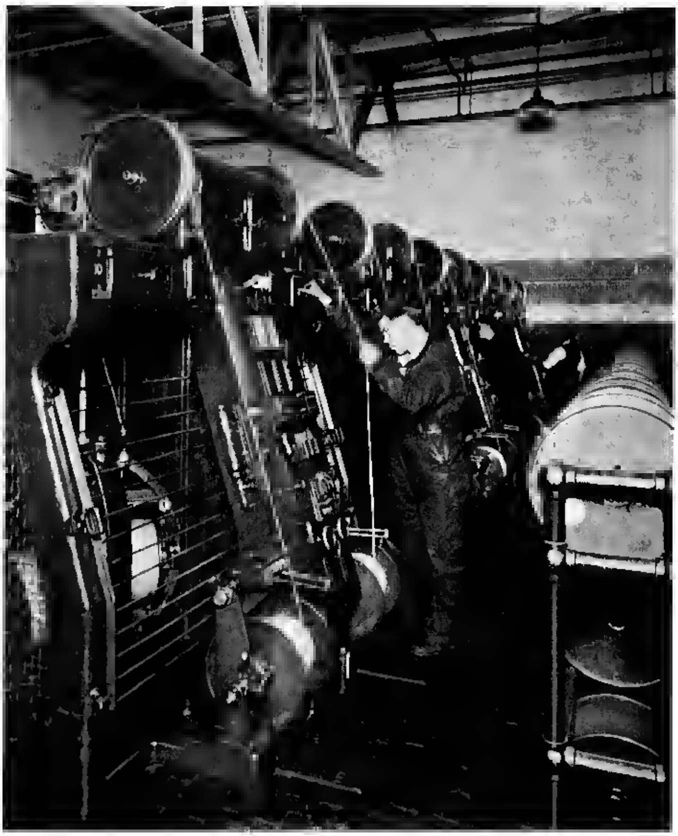


Fig. 7—Twisting and quadding machine.

section of the bottom. These elements are thermostatically controlled so that the temperature of the furnace can be set so as not to cause charring of the insulation as it passes through the drier (Fig. 11). Two spooling positions are furnished at the take-up for each wire, so that as soon as one spool is full, the wire can be shifted to an empty spool, and the full spool removed (Fig. 11). In this way, no shutdowns for

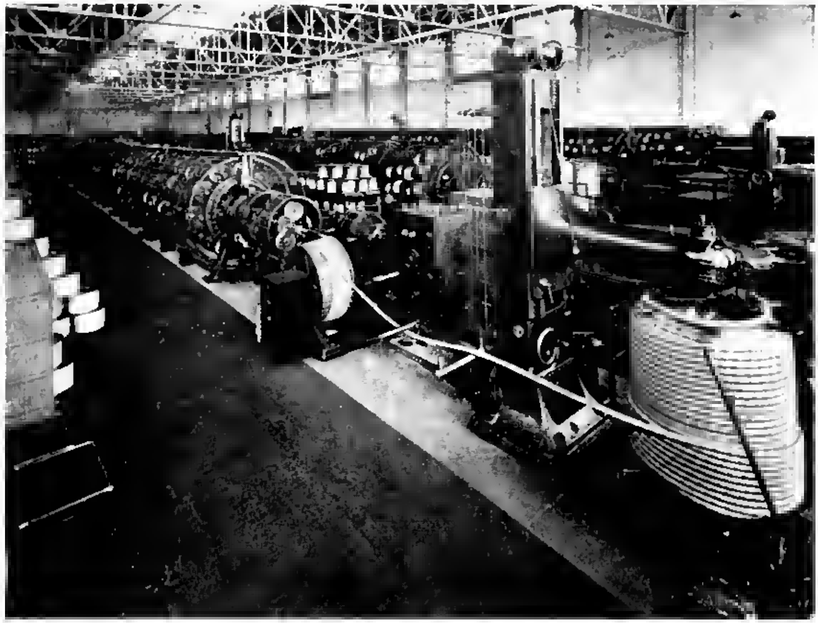


Fig. 8—Stranding machine.

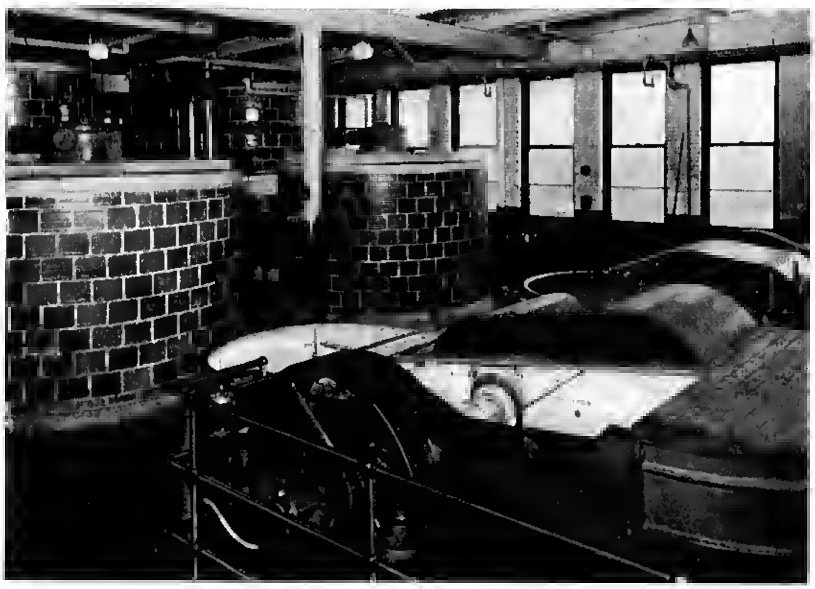


Fig. 9—Beating equipment and pulp storage tanks.

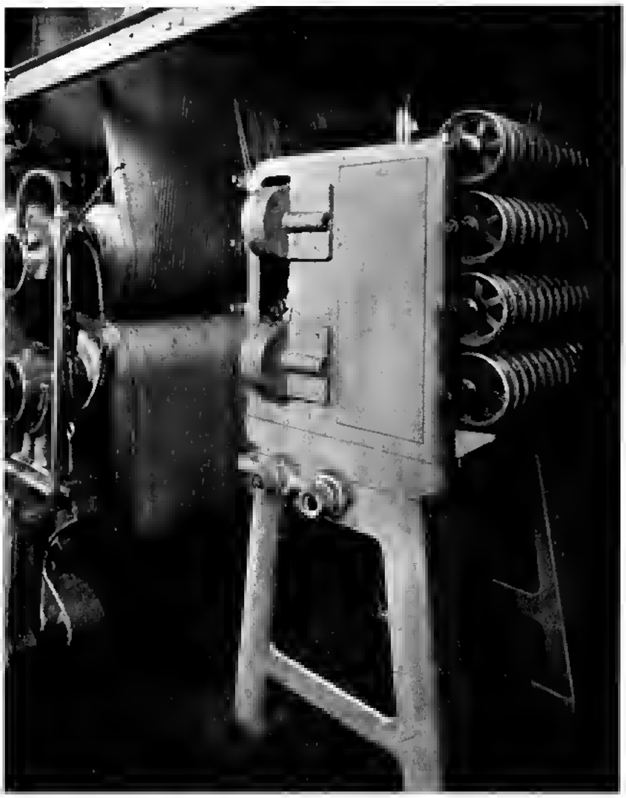


Fig. 10—Machine for polishing pulp insulation after its application to the wire.

Fig. 11—Drying and take-up units.

changing take-up spools are necessary. Individual wires are strung in without shutting down. Tension devices are incorporated in the take-up so as to avoid the possibility of any undue tension being put on the finished wire. The normal speed of the machine is approximately 110 ft. per min., and the output per week is about 45 million conductor feet.

The electrical properties of telephone exchange cables made from this material compare favorably with those made from ribbon insulation, and the annual saving per machine is an appreciable factor due largely to the lower cost of raw material.

Improved Cable Stranding

Until recently all local cable (exchange cable) was built up or stranded by the concentric layer method at a speed of 50 to 100 ft. per min. (Fig. 8). This construction is being rapidly superseded by a unit

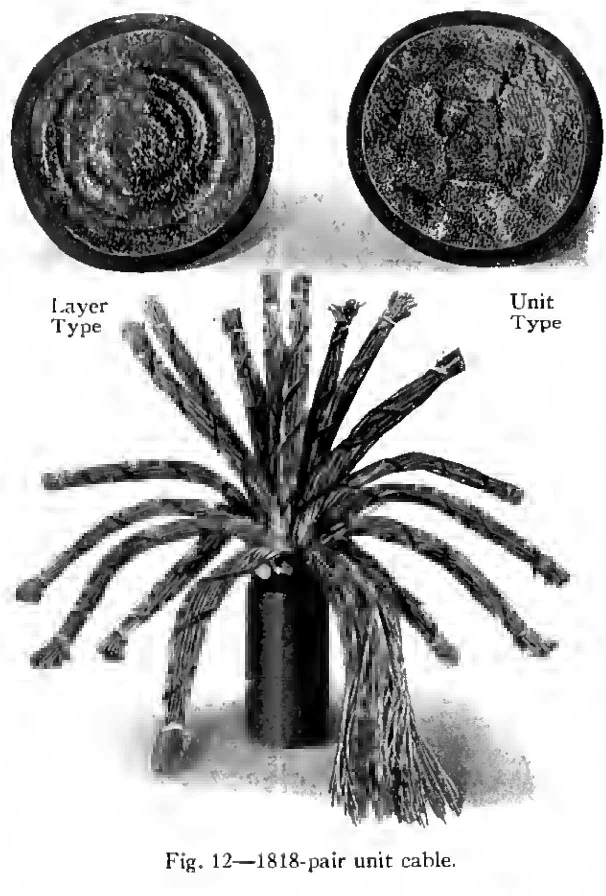


Fig. 12—1818-pair unit cable.

method, the first application of which was made on the 1818-pair 26 B. & S. gauge cable.[7]

The unit method consists of two distinct steps. A flier strander is used to strand pairs into individual color groups known as units, which usually consist of 50, 51, or 101 pairs. A cabling machine then assembles a definite number of these units into a round core form. Thus the final cable size is some multiple of 50, 51, or 101 pairs. An 1818-pair cable built in this manner is shown in Fig. 12.

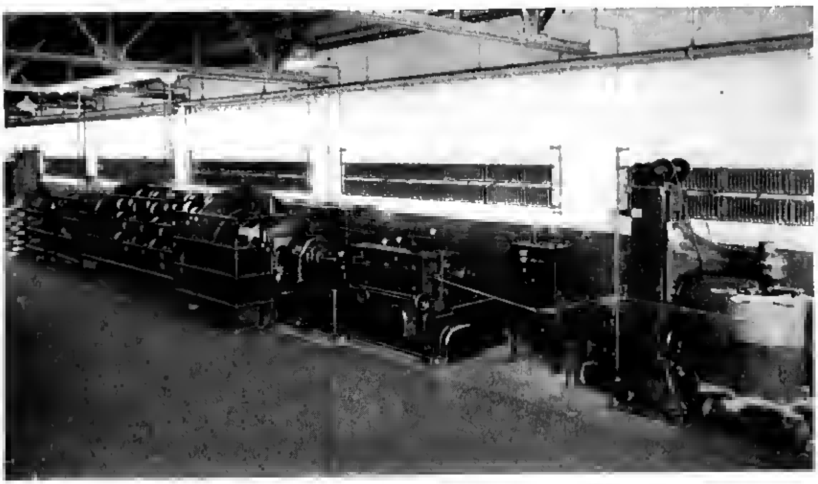


Fig. 13—Flier strander.

The flier strander shown in Fig. 13 consists of a reel carriage or drum for holding 101 supply reels of paired wire; a cotton serving head for winding a cotton thread about the unit; a flier for stranding the unit; a pulling mechanism or capstan for advancing the unit through the machine; and a take-up for reeling the finished unit on a core truck.

By revolving the flier about the normally stationary supply it is possible to obtain two twists in the unit per flier revolution. This combined with the low inertia of the flier permits units to be stranded at the rate of 300 ft. per min.

The cabling machine shown in Fig. 14 consists of 18 supply stands equipped with suitable pneumatic brakes for holding and maintaining tensions on the trucks of units, and a rotating capstan take-up. The units are pulled through a distributer plate and covered with a protective wrap of paper. A twist is put in the cable between the dis-

[7] *Bell Telephone Quarterly*, January 1929, "1800-pair Cable Becomes a Bell System Standard," by F. L. Rhodes.

tributer plate and the entrance point of the cable to the capstan. The finished cable is taken up on reels capable of carrying three times as much cable as the core trucks used with the concentric stranding machine. These reels of cable are then handled through subsequent manufacturing processes by electric trucks.

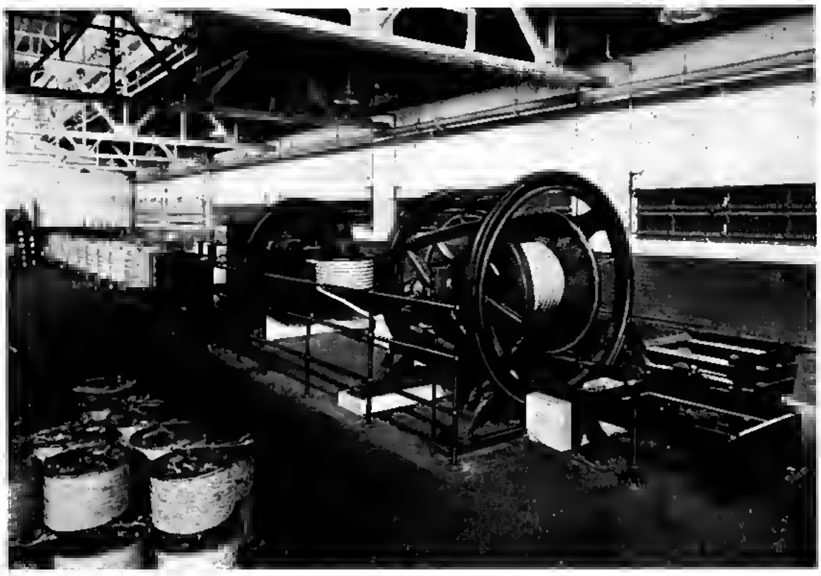


Fig. 14—Cabling machine.

The principal advantages of this construction are that slightly less copper and paper are required in large sizes of cable due to the shorter lay in the outer strands. With the same investment in machinery and building, a much larger production may be obtained. Much finer gauges of wire may be stranded without danger of stretching beyond its elastic limit.

Vacuum Drying

Dry paper is an excellent insulation for the conductors of a telephone cable, but it must be bone dry. Dry paper takes up moisture rapidly and 1000 lbs. loosely packed in a few hours will absorb 90 lbs. of moisture in a room at summer temperature and 60 per cent relative humidity.

A vacuum drying operation is applied to stranded cable prior to the lead sheathing operation at a temperature of 270° F. for a period of from 12 to 42 hours, depending on the size of cable. The vacuum maintained toward the end of the drying cycle is less than 2 in. Hg.

The vacuum drying system installed at the Point Breeze plant has

incorporated in its design many improvements in order to improve cable quality, and also to reduce that part of the manufacturing cost.[8] It consists of fifteen horizontal driers, each 40 ft. in length and $7\frac{1}{2}$ ft. in diameter, and one horizontal drier 40 ft. in length and 10 ft. 4 in. in diameter (Fig. 15). The former driers are used for the ordinary toll

Fig. 15—Vacuum driers.

cable, while the latter single tank is used for drying submarine cables of long lengths.

The drying ovens are arranged so that the loading end is located in the cable room proper, and the unloading end in the dehumidified cable storage room (Fig. 17). To prevent the exfiltration of dry air from the storage room through joints between oven and brick wall a novel type of seal is used. This consists of a flexible sheet of copper, to allow for tank expansion, fastened and gasketed on the inner cir-

[8] For further discussion and detailed factory layout of this system, see paper by J. C. Hanley, *Mech. Engg.*, March, 1931.

cumference to the tank, and on the outer circumference to the brick wall of the storage oven.

Auxiliary equipment used with the vacuum drying ovens consists of two welded vacuum lines (twelve inches in diameter) vacuum pumps, condensers and receiver tanks. A general view can be obtained from Fig. 16.

Fig. 16—Auxiliary equipment for vacuum driers.

One vacuum line is used to establish vacuum in a new tank load of cables, and the second is used for maintaining vacuum in the tanks once they have reached the proper point. The pump equipment consists of four reciprocating feather valve vacuum pumps. The pistons on these pumps have a diameter of twenty-nine inches and a stroke of eighteen inches or a displacement of ten hundred and twenty five C.F.M. The pumping capacity has been based on maintaining absolute pressures of one-half to one inch in the vacuum tanks. These values are based on a vacuum tank activity of eighty-five per cent and on maximum leakage of approximately twenty pounds of air into each tank through the door gaskets.

Two two hundred and twenty five C.F.M. surface condensers are incorporated in the layout ahead of the pumps to condense moisture given off by the insulated paper. Three thousand pounds of water may be extracted in twenty-four hours.

New features incorporated in the oven are design changes of the heater coil and tank. This coil, of which there are four in each oven, consists of steam header inlet and outlet, instead of a continuous

length of eleven hundred and twenty feet of pipe. This type of coil not only makes a much neater appearance in the heating system due to its rigidity, but also insures positive draining, with the elimination of steam hammer, and also more uniform heating in all portions of the tank. The tanks are completely welded instead of riveted. This method of assembly insures a better average vacuum as well as eliminating considerable maintenance work in caulking rivets, which become loosened by the repeated expansion and contractions of the drier.

Cable Storage Prior to Lead Covering

The air conditioned room (Fig. 17) is provided for the storage of cable prior to lead sheathing in order to facilitate the covering of varying

Fig. 17—Air conditioned cable storage room.

diameters of cable with a minimum of lead-press die-block changes, and also to act as a reservoir for the fluctuating delivery of large quantities of vacuum-treated cable. An alternative, that of storing cable in the vacuum driers until ready for lead covering would require an excessive investment in vacuum drying tanks and their operation.

The storage room, from which the cable is paid out directly to the presses, is approximately 270 ft. long, 50 ft. wide and 12 ft. high, and has been designed to prevent infiltration of moisture. Without moisture proofing, the outside wet air would penetrate a concrete or brick wall since the vapor pressure in the storage room is only approximately .007 in. Hg as compared to 1.02 inch outside the room on a hot humid day. The moisture proofing was accomplished as follows: An aluminum foil was placed over the inner surface of the outer portion of the brick wall. This foil was suitably protected by a layer of saturated rag felt and roofers asphalt. The remainder of the brick wall was

placed in position over the moisture proofing membrane. The floor was prepared in a similar manner.

The concrete ceiling of the room was covered with a layer of aluminum foil suitably overlapped and held in place by varnish.

As an added protection, all entrances are vestibuled and all cable ports are equipped with air tight cable tubes leading to the presses. When the press is not in use an air tight door is closed over the inner end of the cable port.

Air Conditioning Equipment

The primary object in drying toll cable is to obtain as low conductance and capacitance values and as high insulation resistance as possible. This has a very important effect on the transmission quality of the cable, and consequently justifies considerable expense.

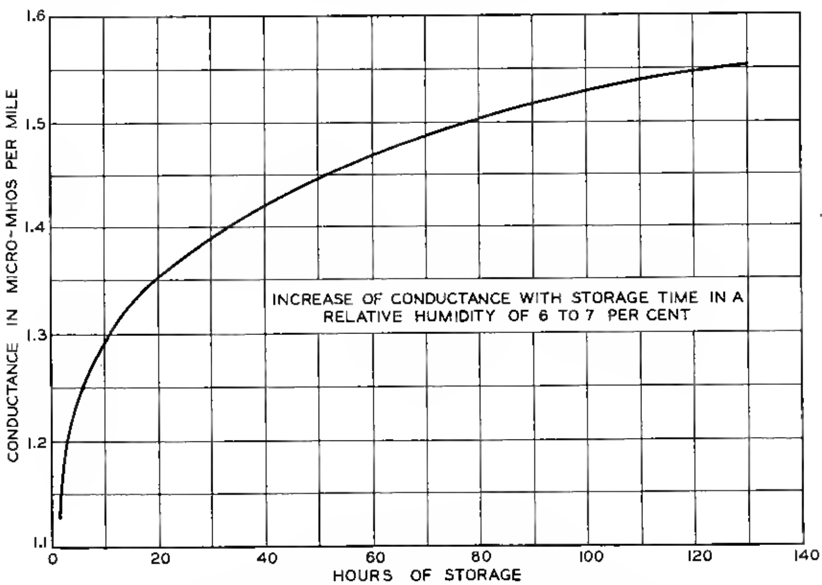


Fig. 18—Effect of moisture regain on conductance of vacuum dried cable.

A large amount of experimental work has been done to determine the best methods of obtaining and retaining dry cables. At the end of the vacuum drying cycle the cable paper is in such a dry condition that its moisture regain when exposed to higher humidities is exceedingly rapid. This is indicated by Fig. 18, showing the increase in conductance over a period of hours when dry cable is exposed to approximately 6–7 per cent relative humidity.

Working from these data and an estimate of the manufacturing ad-

vantages from storage due to the elimination of lead press changes, it was decided that a minimum moisture condition of .5 of one per cent with storage periods not greater than 24 hours would result in minimum conductance and capacitance values consistent with manufacturing costs. The limit of .5 of one per cent was decided upon since to maintain humidities lower than that, costs would increase very rapidly and entirely out of proportion to the change in relative humidity conditions and the final result.

The air conditioning equipment installed at the Baltimore plant is unique, in that a relative humidity of .5–.8 per cent is maintained at a temperature of 100° F. without resorting to refrigeration. Silica gel, highly porous form of silicon dioxide, or sand, is used as the water absorptive medium. Before deciding upon this method of dehydration other existing types of equipment were investigated. To obtain such low humidities with the usual types of dehumidification systems would require more than one stage of cooling and result in more expensive operation costs in comparison with silica gel units.

The design requirements of this equipment were based on data established for the following:

(1) Heat losses in the walls and infiltration of moisture.
(2) The movement into the storage room of core trucks filled with dry cable at temperatures of approximately 260° F., and the incident rush of storage room air into the vacuum driers when the vacuum was broken.
(3) The loss of conditioned air when cables are being pulled through the bell mouth openings to the press and also when the storage room doors are opened.
(4) The actual moisture content of outside air, which must be dried to replace losses in the storage room.

Based on a summary of the B.T.U. losses and gains which could be expected in the manufacturing process, a study of the Baltimore temperature conditions over a period of years, and an analysis of the humidity conditions which would be encountered, equipment was designed which will handle a volume of 13,000 cu. ft. of air per minute amounting to a complete change of room air five times per hour. Of this total amount approximately 10,300 cu. ft. is re-circulated, cooled, dehydrated and brought back to the storage room requiring adsorber capacity for only .6 pound of water per minute. Twenty-six hundred cu. ft. of air is drawn from the outside to compensate for air losses at various points in the room and to maintain an overall room pressure of about $\frac{1}{2}$ ounce in excess of outside air pressures, requiring additional adsorber capacity of approximately 4 pounds of water per minute.

To maintain a normal operating temperature, it is necessary to remove 17,500 B.T.U.'s per minute. This is accomplished by cooling the air which is re-circulated plus the fresh air taken into the system to 72° F.

The method of air distribution within the storage oven was carefully designed since the rate of regain of moisture by paper insulated cable is dependent not only on the difference in vapor pressure of the cable paper itself and that of the air passing over it but also on the velocity of the air. The dry air is supplied through grill openings along the side of the room at approximately 3–4 ft. from the floor, and at low velocities consistent with positive circulation. Thus the driest air is supplied at the point where it is most needed and, since the return

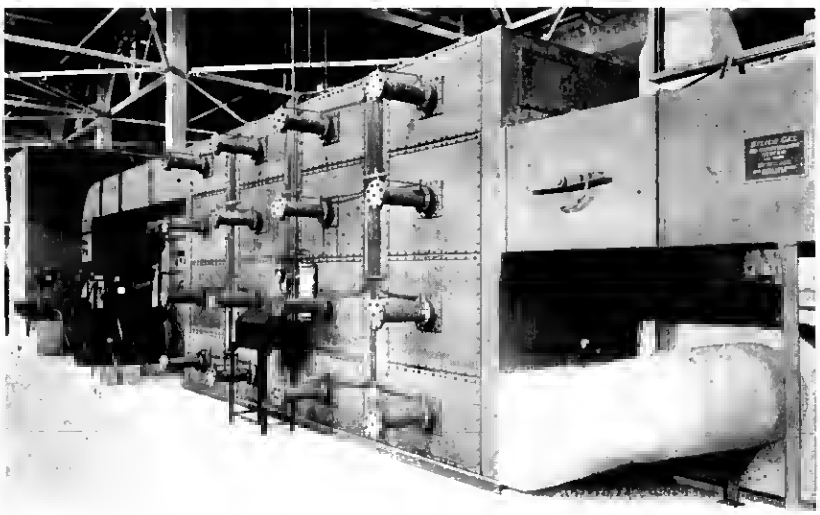
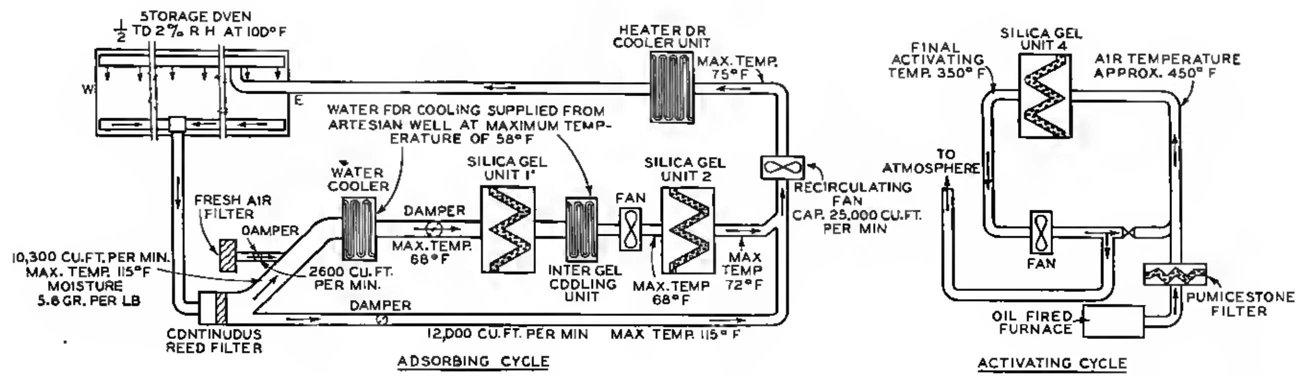


Fig. 19—Silica gel drying unit.

ducts are located at the ceiling opposite to the grill openings, any regain of moisture in the room itself is largely concentrated in air strata above the cables.

Operation of the Baltimore conditioning system (Fig. 19) may be described briefly as follows: Approximately 10,300 cu. ft. of air per minute from the storage room is mixed with 2600 cu. ft. per minute of outside fresh air. The temperature of this air mixture which may be as high as 100° F. is lowered to a maximum of 68° F. by passing it over and around copper tubes through which water at 58–60° F. is circulating. The cool air then passes through the first silica gel adsorber where it is partially dehydrated; then it is again cooled and is passed into the second adsorber where the drying is completed and from which



COMPLETE AUTOMATICALLY OPERATED CYCLE				
CYCLE	UNIT 1	UNIT 2	UNIT 3	UNIT 4
1	ADSORBING 1	ADSORBING 2	COOLING	ACTIVATING
2	ACTIVATING	ADSORBING 1	ADSORBING 2	COOLING
3	COOLING	ACTIVATING	ADSORBING 1	ADSORBING 2
4	ADSORBING 2	COOLING	ACTIVATING	ADSORBING 1

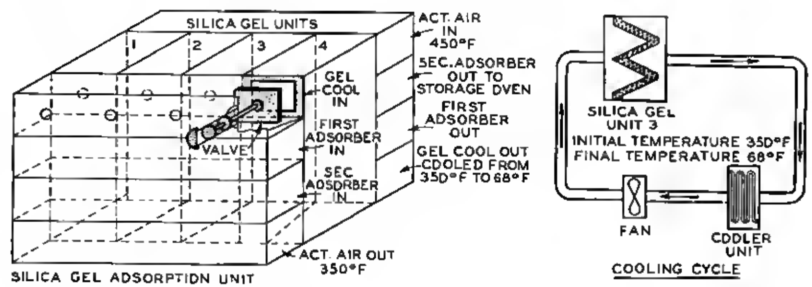


Fig. 20—Operating cycles on silica gel unit.

it passes to the supply ducts in the storage room. The system is so constructed that there are three simultaneous cycles (Fig. 20): one in which the silica gel is used as an absorbent, the second where it is reactivated, and the third where a freshly reactivated bed is cooled to 68° F. Automatic controls switch the air currents into their respective channels at established intervals. The condition of the vital parts of the system is indicated continuously on a control board where temperatures, air volumes, and relative humidities [9] are shown.

Lead Sheathing

The thoroughly dried cable core passes from the storage oven through a tube, designed to minimize any exposure to outside air, into the press where it receives its protective cover of lead. The

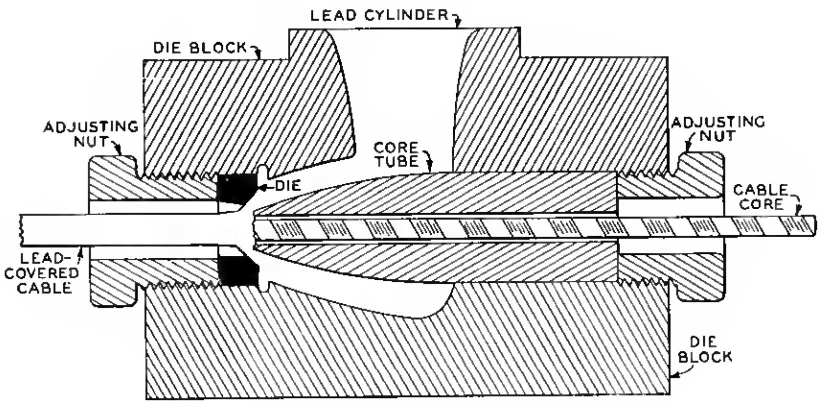


Fig. 21—Cross section of typical die block.

basic principle of applying lead sheath to cable is illustrated by Fig. 21 which shows a cross-section of a typical die block. This die block consists of a core tube and a die, ring shaped, mounted in a hollowed-out block. This arrangement provides an opening adjacent to the cable core which aids in definitely controlling the thickness and diameter of the sheath. This die block is placed underneath a large cylinder for receiving molten lead, and both are placed in a hydraulic press.

In covering large cable, more than half of the total time is taken up in filling the cylinder with lead and cooling it under pressure to a point where it can be extruded. The tendency, therefore, has been to build presses with larger lead containers, and in turn of larger capacity,

[9] Page 134, Vol. 2, *Industrial and Engineering Chemistry*, April 15, 1930—article by A. C. Walker and E. J. Ernst, Jr.

in order to make the productive time of extrusion a larger percentage of the complete cycle of operation. Until recently presses were used having a 30 in. diameter ram and a 42 in. stroke. Such a press has a capacity of 1100 lbs. of lead per charge and extrudes a maximum of 4500 lbs. per hour. This type of press has the water ram located below the floor line. The die block and lead cylinder therefore rise slowly as the lead is forced out around the cable core. This varying height of the cable as it is extruded in relation to the floor introduced some difficulties in the operation.

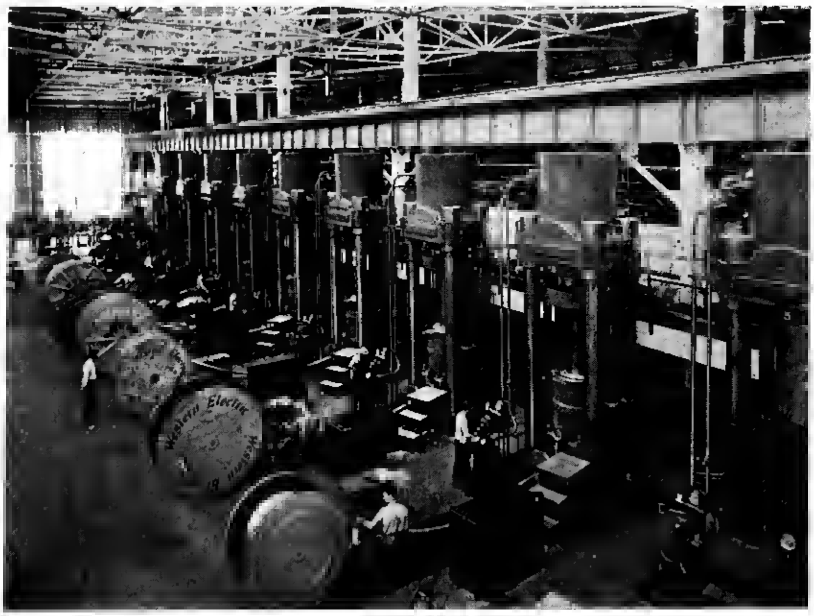


Fig. 22—34-in. inverted press.

The latest type of press used at Baltimore is illustrated by Fig. 22 and is known as the 34 in. inverted press. It was designed and built by one of our outstanding American engineering firms. Its stroke is 56 in.; the diameter of the ram is $10\frac{1}{2}$ in., with a lead capacity of 1800 lb. per charge and a maximum extrusion rate of 5680 lb. per hour. This press is approximately 21 ft. in height above the floor line, and has the water cylinder mounted between the four columns at the top of the press. The 34 in. diameter water ram has the steel lead ram bolted to it. Connection is made from the water cylinder to a hydraulic pump, Fig. 23, supplying water at a maximum pressure of

5500 lb. per sq. in. The four steel columns supporting these top castings are $12\frac{1}{2}$ in. in diameter. The steel ram exerts during extrusion a pressure of approximately 59,000 lb. per sq. in. on the lead. At the floor level of the press there is a cast-steel plate which carries a steel spacing block upon which the die block rests. Above the die block is a water-jacketed lead cylinder which is exactly centered over the feed orifice of the die block. The die block and lead cylinder are held in place on the cast-steel plate by four $2\frac{1}{2}$ in. bolts. All these parts are stationary on this press, facilitating handling and inspection, and insuring that the cable core always enters and leaves the die block at the same angle.

Fig. 23—Lead press hydraulic pumps.

The concentricity of the sheath is affected not only by the contour of the extrusion chamber, including core tube and die, but also by the manner in which heat is applied; and the thickness is affected by temperature and speed of extrusion so that the human element is an important factor, and it is necessary to have thoroughly trained and reliable operators on this kind of work. Temperature indicators are used to show die-block temperatures, and the temperature of the molten lead is automatically controlled and recorded.

Aside from increasing output, many studies have been made to determine the exact mechanism of lead extrusion, the relative flow of lead in different parts of the extrusion block, the effect of application of heat at different points, etc.

As the lead-covered cable leaves the press, it is wound upon either

wood or steel reels, depending upon its type. A full reel may weigh as much as 10,000 lbs. These reels are rotated by means of power-driven floor rolls which are controlled by the press operator's helper. After the reel was filled with cable, it was formerly the practice to push the reels off the rolls manually. The latest type of floor rolls are equipped with automatic ejector devices which lift one roll and cause the loaded reel to roll off on the floor. This is done by means of a small hydraulic cylinder connected to a pump which is operated by a valve mounted adjacent to the floor rolls.

The Central Lead-Melting System

In order to supply the presses just described, large quantities of lead-antimony alloy must be delivered frequently. The old and new arrangements are shown in Fig. 24. With the old arrangement lead

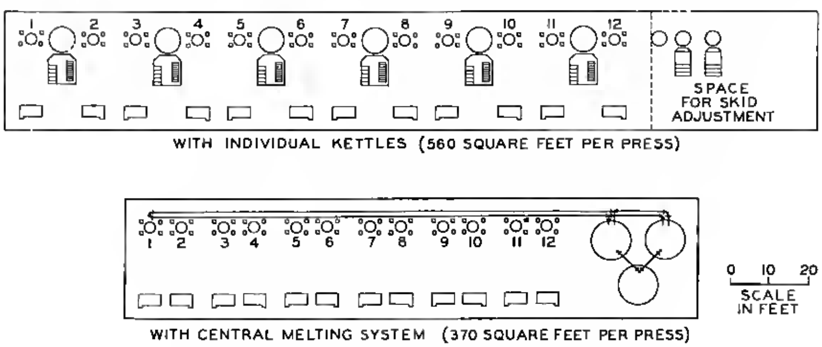


Fig. 24—Space required for 34-inch inverted presses.

was delivered in skids by an overhead traveling crane to small melting kettles adjacent to each pair of presses. This arrangement also involved considerable manual handling, and introduced some variation in the finished alloy sheath.

The new arrangement consists of melting all of the lead alloy in a large furnace at a central location and distributing this molten lead through a long-loop pipe line running back of the presses. Near each press a loop branch from this line is made and equipped with the proper kind of control valve. This line is heated electrically and the lead is in constant circulation. Such a system was built on a small scale and tested under continuous operation for over a period of six months, at the conclusion of which it was considered entirely feasible to incorporate it as a part of our new Baltimore plant. In order to take full advantage of such a system, the presses were placed

close together, thus saving the space formerly occupied by the small individual melting kettles, and the large central-supply kettles were placed adjacent to the lead storage pit in order to minimize handling. Views of this system now in use at Baltimore are shown in Figs. 25–28.

The details of this central lead-melting and distributing system will be of interest to manufacturers using large quantities of lead or lead alloy. Three oil-heated kettles are used (Fig. 25), and pipe and valve arrangements have been set up so that the middle kettle is used for melting and preparing the alloy to the exact composition. The second kettle

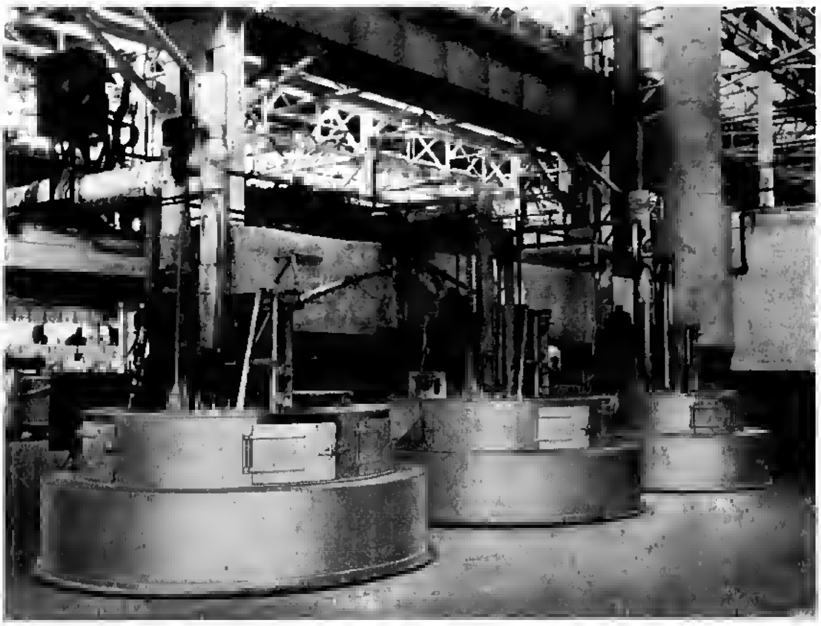


Fig. 25—General view of melting and supply kettles.

is used as a main supply and connected up to the distributing system. The third kettle is a spare, and the piping is so arranged that it can be used either as a melting or supply kettle. Each kettle has a capacity of 120,000 lbs. of lead, and the melting capacity of the system is 80,000 lbs. per hour. Space is provided for a fourth kettle to take care of the ultimate expansion of the cable plant.

Each kettle has two sets of low-pressure oil burners installed diagonally across from each other. An impeller type of vertical pump having its intake about 12 in. above the bottom of the kettle, and driven by a 20 hp. vertical motor, creates sufficient agitation by the circulation of the metal to assure a uniform composition.

The charging of the melting kettle with virgin lead is accomplished by means of a specially designed lead-handling grapple (Fig. 26) which has a capacity for 100 billets of the standard size or a total weight of about 8500 lbs. Five to six of these charges or about 40,000 to 50,000 lbs. constitutes one melting cycle. The corresponding amount of

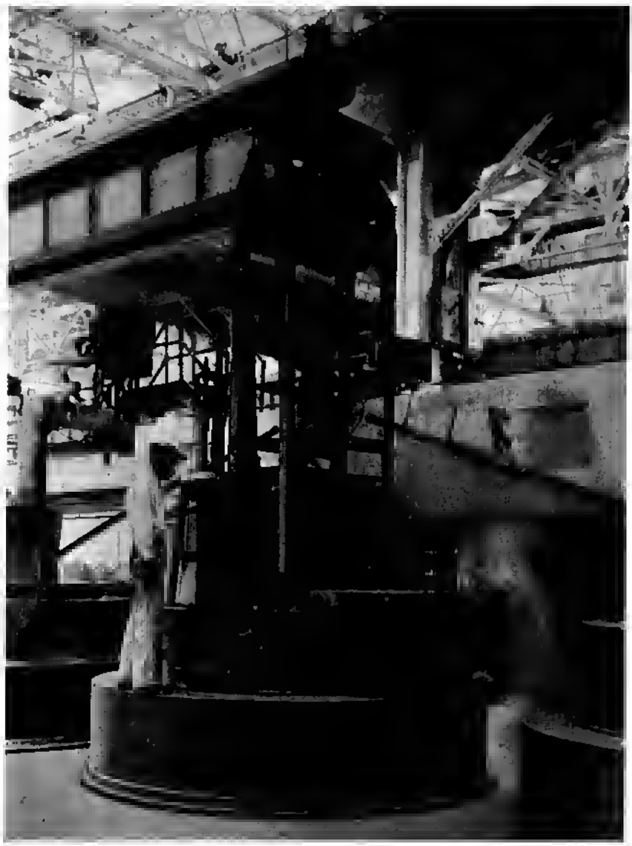


Fig. 26—Charging of lead-melting kettle.

antimony is loaded into a special cradle which moves in a separate chamber and is lowered below the surface of the lead, where the antimony is dissolved by the washing action of the stream of lead from the return line of the pump (Fig. 27).

The supply kettle is charged with the desired amount of molten lead of the correct composition and temperature from the melting kettle by means of the pump on the transfer line. Each kettle has one recording

controller for regulating the temperature and one controller as a check instrument and to actuate an alarm if the temperature goes above or below a predetermined limit. Each instrument has its own thermocouple.

To reduce to a minimum the possibility of a prolonged shutdown due to a breakdown in the lead conveying line, a duplicate pipe system

Fig. 27—Antimony charging mechanism.

is provided which can be put into service in a short time in case of failure of the line in use. The line ordinarily used is the one nearest to the presses and is the service line while the line one foot to the rear but at the same height, is called an emergency line.

The main-line piping system is made of seamless steel tubing supported on a roller-conveyor system to take care of the expansion and contraction which amounts to $6\frac{1}{2}$ in. per 100 linear feet at 750° F. or a total of approximately 20 in. under normal working conditions for the

system. The down spouts are of seamless steel tubing and have a steel valve at each joint with the main line and a service valve at one corner of the "U" bend. All joints are oxyacetylene welded, and no fittings are used throughout the system. The lines are insulated with pipe covering protected by a layer of fireproofed canvas (Fig. 28).

The lines are heated initially by a series of transformers which supply a low-tension, high-amperage current directly into the pipe by forming a loop of the supply and return line. Once circulation of the lead has been established in the piping system, the main line requires little additional heat from the transformers, as the flow of the

Fig. 28—Main lead supply lines.

lead will ordinarily keep the line up to temperature. Approximately 4 KVA are required on each down spout while in use. The connections leading from the transformer to the pipe are flexible, to allow for expansion and contraction of the system.

Switches are provided on each building column opposite the presses to enable an operator to shut down the pumping system in case of a serious leak or failure of a valve.

This system has been in operation for about nine months and has resulted in a higher quality of lead sheath due to more uniform composition maintained. In addition there are considerable savings in fuel, reduction in dross, and elimination of a large amount of heavy manual effort. The press room is now clean and cool, resulting in much better working conditions and in turn an indirect improvement in the quality of the product.

Testing Lead Covered Cable

After the cable is stranded each conductor is tested from end to end for continuity and against every other conductor for crosses. Defects are repaired and after the cable core has been dried the lead sheath is applied. After the application of the sheath the cable is allowed to stand until it cools to room temperature. Fig. 29 shows the cooling floor and test mezzanine in the Point Breeze cable plant. The reels of cable issue from the lead presses at the right; are cooled in the central area and tested beneath the mezzanine at the left.

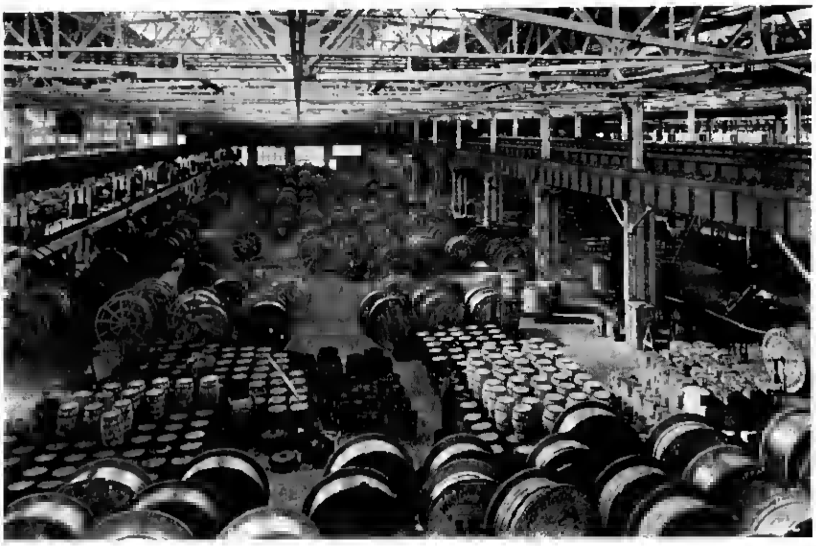


Fig. 29—Cooling floor and test mezzanine.

When the cables are cooled the conductors are given a final test for opens and crosses which may have developed due to strains imposed during the sheathing process. Most toll cables have a number of spare wires and if fewer than the allowable number of above defects are found the cable is tested for dielectric strength, insulation resistance, mutual capacitance, capacitance unbalance and defects in the sheath. Dielectric strength tests are made between each conductor and every other adjacent conductor to which failure may occur and between all conductors and the lead sheath. The potential used for these tests ranges between 350 volts, A.C., the lowest value used for certain conductor to conductor tests and as high as 5,000 volts, A.C. for some conductor to sheath tests. In making the conductor to conductor tests a large number of circuits are involved so that interesting prob-

lems arise in designing switching devices to apply the test potential between all conductors.

Defects found by continuity, cross or dielectric strength tests must be located within the cable in order that repairs may be made. The point of break in open conductors is located by comparing the capacitance between the defective conductor and the adjacent conductors with the capacitance between a conductor known to be good and its adjacent conductors. Preliminary locations of crosses between conductors and between conductors and the sheath are made by means of the modified Murray Loop test. Final locations are made by means of a search coil and telephone receiver which responds to currents of audible frequency circulated through the crossed conductors.

Fig. 30—Typical test set installation at Baltimore plant.

Fig. 30 shows a closer view of a section of the test mezzanine at the left of the cooling area. The test desk in the foreground is designed for making insulation resistance, D.C. capacitance, A.C. capacitance, and conductor resistance tests. The test desk in the center is a shielded precision bridge for making capacitance and conductance measurements at audio frequencies. Two test desks in the background are capacitance unbalance bridges. All desks on the mezzanine floor are provided with test leads which terminate in outlet boxes on the test floor below.

Figs. 31 and 32 show a front and rear view respectively of the

insulation resistance, D.C. capacitance, A. C. capacitance meter, and conductor resistance test desk which appears in the foreground of Fig. 30. Insulation resistance measurements are made between conductors and between all conductors and the sheath by observing the deflection obtained with a high sensitivity reflecting type D'Arsonval galvanometer through which a potential of 500 volts D.C. is impressed on the insulation of the conductors under test. Due to the

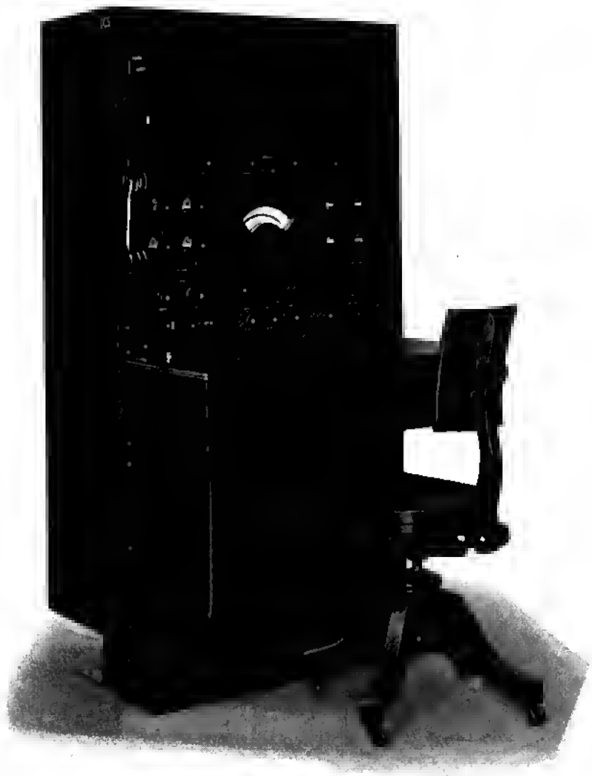


Fig. 31—D-C. insulation resistance test desk—front view.

high insulation resistances involved and the extreme sensitivity of the measuring circuit, considerable difficulty is likely to be encountered with leakage in the test apparatus itself, especially during times of high relative humidity. To overcome this source of error special test circuits have been designed which employ a shield (Fig. 33) to eliminate from the measurement all extraneous leakage other than that of the cable. The direct reading capacitance meter is used extensively for

mutual capacitance measurements where the highest accuracy is not essential and where conductance readings are not desired. D.C. capacitance tests are made by the charge and discharge method, employing a ballistic galvanometer. In general, D.C. capacitance tests are not fully indicative of the characteristics of the cable at telephonic frequencies and for this reason are not extensively employed.

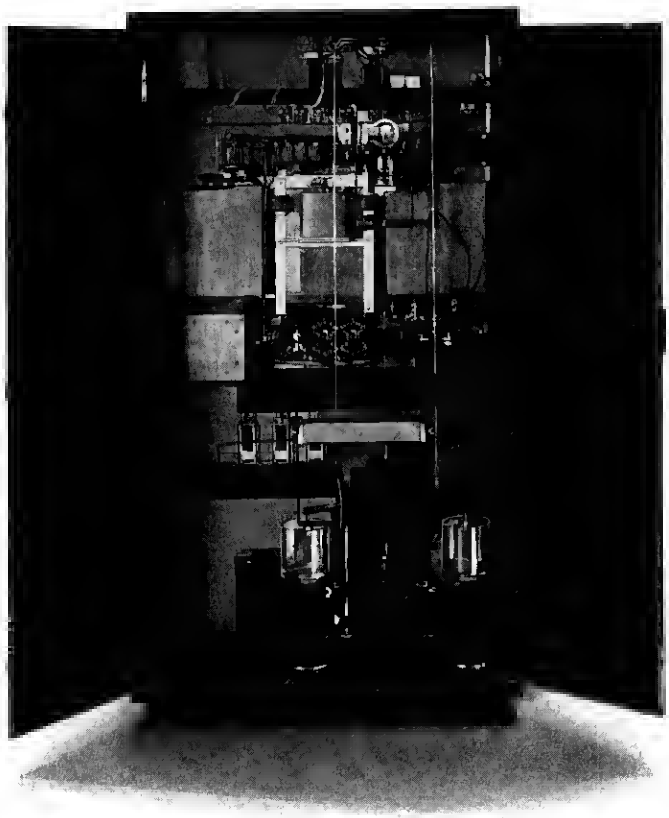


Fig. 32—D-C. insulation resistance test desk—back view.

Conductor resistance tests, Fig. 34, are made by means of a Wheatstone bridge circuit specially arranged to read directly the conductor resistance per mile at 68° F.

Although the majority of mutual capacitance measurements are made by means of the direct reading capacitance meter, the capacitance and conductance of a percentage of all cables are measured at a frequency of 900 cycles per second by means of the shielded capacitance

bridge.[10] Due to the fact that these bridges are frequently employed in shop areas where some noise exists it has been necessary to develop a

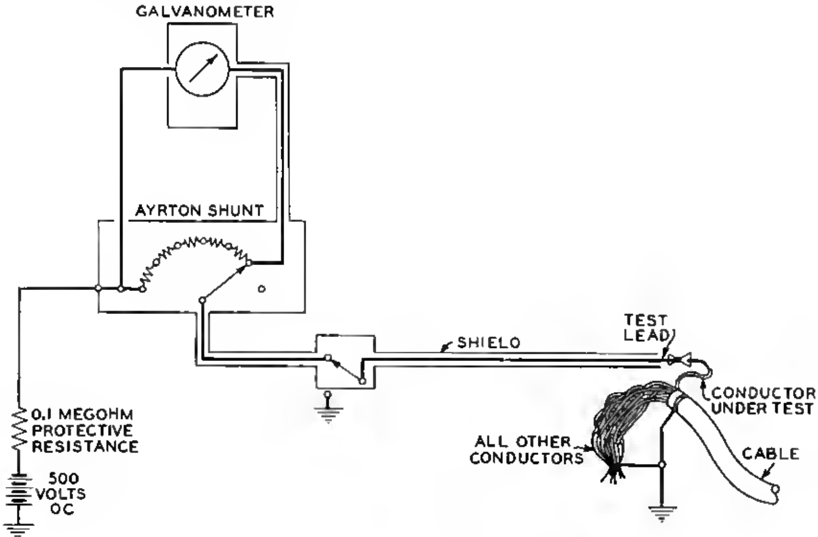


Fig. 33—Shielded insulation resistance test circuit.

device to replace the telephone receiver as a means of indicating bridge balances. The visual bridge balance indicator used consists essentially of a vacuum tube circuit in which the alternating current

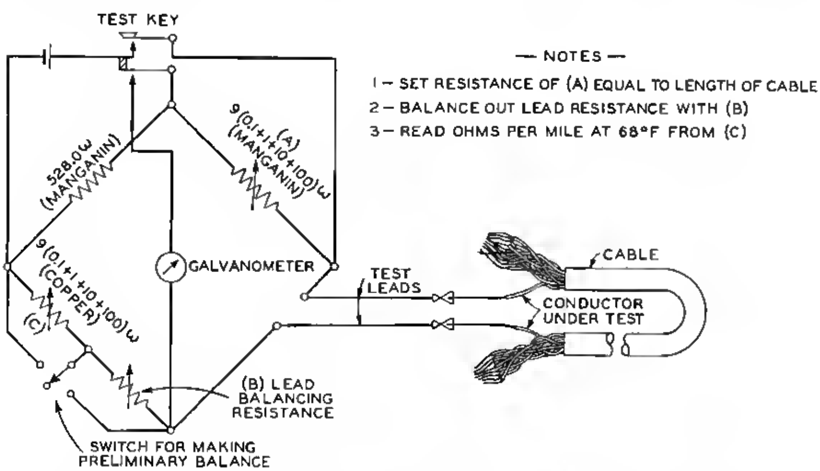


Fig. 34—Conductor resistance measuring circuit.

[10] *Bell Sys. Tech. Jour.*, July, 1922: "Measurement of Direct Capacities," G. A. Campbell. *Transactions A. I. E. E.*, Vol. XLVI, May, 1927: "High Frequency Measurement of Communication Apparatus," W. J. Shackelton and J. G. Ferguson.

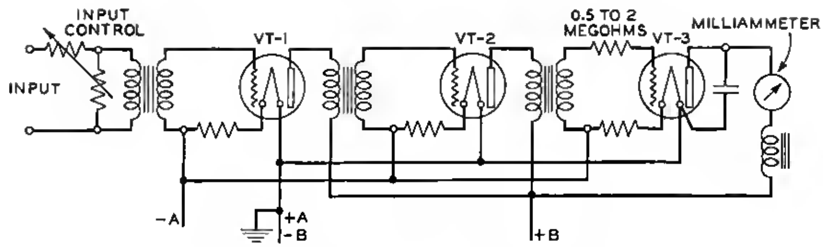


Fig. 35—Visual bridge balance indicator circuit.

input to the indicator is amplified and the rectified output is indicated by the reading of a D.C. milliammeter. When the bridge is balanced there is no input to the indicator so that the milliammeter pointer

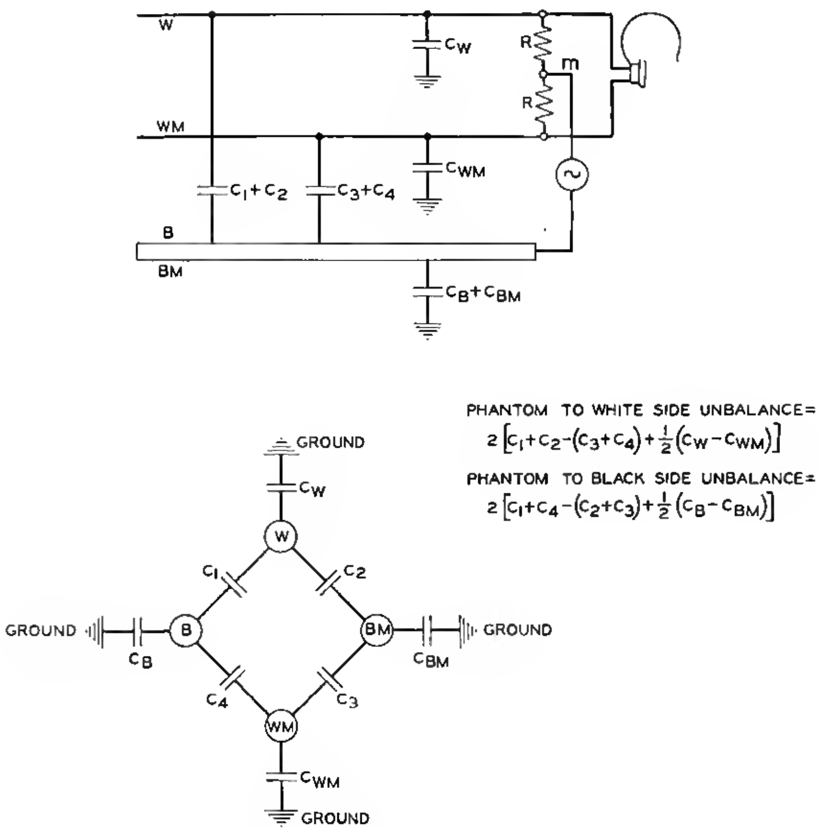


Fig. 36—Phantom-to-side capacitance unbalances.

returns to the lower end of the scale, See Fig. 35. The high resistance in series with the grid of the third or rectifier tube prevents the overloading of the milliammeter when a large input voltage is impressed on the indicator circuit.

Toll cable in addition to the above receives a capacitance unbalance

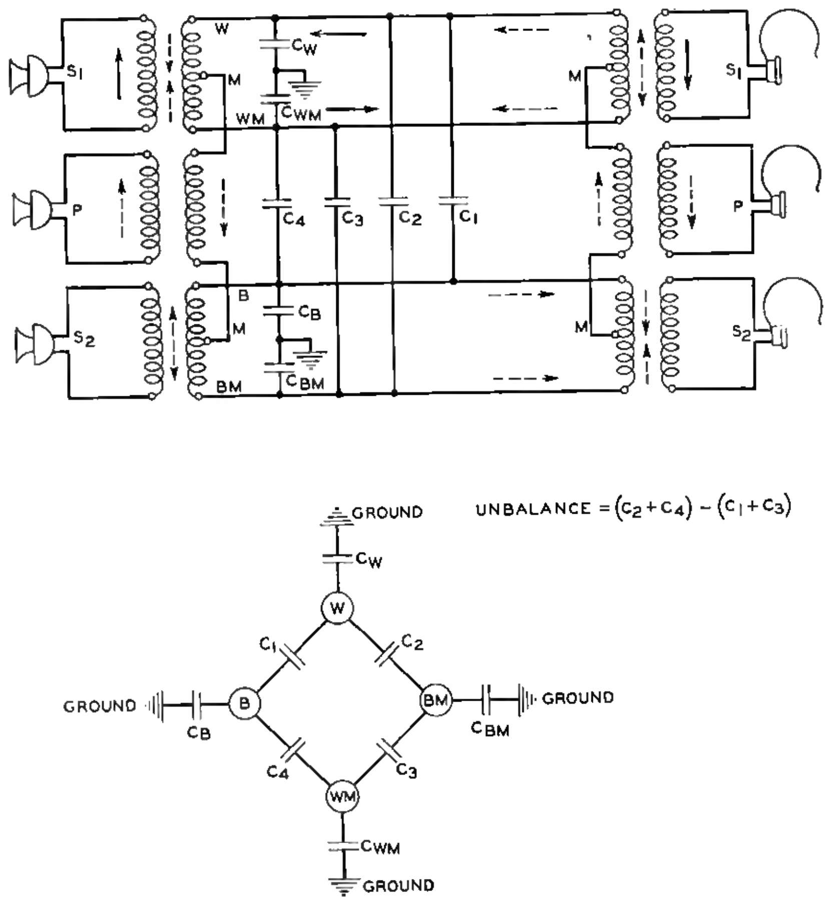


Fig. 37—Side-to-side capacitance unbalances.

test which is indicative of the cross-talk existing between circuits. These tests are made with a special shielded bridge mentioned above, which measures the capacitance unbalance between side and phantom and side circuits of "quads" (Figs. 36 and 37). These bridges are also provided with visual balance indicators as described above.

After the cable has successfully met all electrical requirements both

ends are sealed and the cable is prepared for shipment. Certain types of cable receive an additional gas pressure test to detect minor defects in the lead sheath which otherwise may have escaped attention. Dry nitrogen is forced into the cable to a predetermined pressure and the cable is allowed to stand for a specified period. Loss of pressure during the test period indicates that the sheath or seals contain one or more defects.

Armoring of Telephone Cable

Two types of armored telephone cable are in use, Fig. 38. Submarine telephone cables for rivers and harbors are usually protected by

TAPE ARMORED CABLE

SUBMARINE CABLE

Fig. 38—Typical construction of tape and wire armored cables.

layers of jute and wire placed on the outside of the lead sheath. This type of armor is quite familiar and is called wire armoring. Cable buried in a dirt trench is armored in a similar way except the wire is replaced by two layers of steel tape. This is called tape armoring. It is adapted to certain localities where there are long stretches of open country and the conditions indicate one or two cables will handle the requirements for a considerable number of years.

A typical wire armor is made up of a bedding of 100 or 150 pound jute roving, impregnated with suitable preservative after serving, by passage through immersion troughs, over which a layer of armor wires is applied. In some cases, a covering of outer jute flooded with coal tar is used. When an unusual degree of protection is desired, a second layer of armor wire is applied. In such cases a bedding of jute is used between the layers.

Recent trends in the design of wire armored cables are leading toward cables of much larger diameter. At the Point Breeze plant there is an unusually large wire armoring machine (Fig. 39). It is designed to handle cable up to $5\frac{1}{2}$ inches in diameter over the armor.

Tape armored cable differs somewhat in construction depending upon the kind and diameter of cable armored. A typical design is made up as follows: A coating of asphalt is first applied to the cable and over this a layer of impregnated kraft paper. Another layer of asphalt compound is put on and then two servings of impregnated jute roving

Fig. 39—Wire armoring machine.

with opposite directions of lay. Asphalt coatings are used between the two servings and on the outside of the second. Next two steel tapes are served with the same direction of lay and with the second tape overlapping the gap between the edges of the first. Again the cable is given a coat of asphalt. One serving of impregnated jute roving, a coating of asphalt and a layer of impregnated jute yarn with opposite direction of lay are next applied. An application of non-adhesive compound composed of whiting, glue, and water completes the armor coating. The machines used for tape armoring are shown by Fig. 40. They consist of a supply position for the lead sheathed cable, asphalt tanks, paper heads, jute heads, two steel tape heads, a capstan and take-up. Tanks for melting the asphalt compounds before their use in the machine are also provided. This

type of cable is protected from mechanical injury and soil corrosion, and can be laid very quickly and cheaply. One interesting advantage gained through the use of this type of armor is that a magnetic shield is thus placed around the cable greatly reducing the effects of induction.

Fig. 40—Tape armoring machine.

Conclusion

The application of scientific and engineering effort to improvements in the processes and machine equipment for manufacture of telephone cable is fully justified by the results which have been obtained from both an economic and quality standpoint. New raw materials and alloys together with new designs of cable will be forthcoming in the future in the effort to improve and extend the long distance telephone service. New communication devices will be invented and perfected for use in connection with such cable and these in turn will have a radical effect upon the cable design, the process and the equipment for its manufacture. The engineers and scientists engaged in such manufacturing activities are indeed rendering a broad service not only to the men and women employed in the immediate industry but also to the people at large who use these facilities.

In concluding, the writer wishes to acknowledge the efforts of the men who have carried these developments to a conclusion, in particular Mr. H. G. Walker on the pulp wire process; Mr. L. O. Reichelt and Mr. H. J. Boe on the unit cable machinery; Mr. H. F. Carter on the central lead melting system; and Mr. J. Wells on the air conditioning system.